CHAPTER 4 — PRETREATMENT: DISINFECTION FOR BIOTA TRANSFER CONTROL

To ensure compliance with the Boundary Waters Treaty of 1909, water from the Missouri River drainage basin, prior to delivery to the Red River drainage, must be pretreated to inactivate aquatic biota, including fish, larvae, fish eggs, algae, viruses, bacteria, and protozoa. This requirement arises from the fact that the Missouri is part of the Mississippi drainage system, whereas the Red River drains ultimately to Hudson Bay; thus, any water transferred from one to the other crosses a major divide not only between drainage basins but also between ecosystems.

Many studies have been done to determine what treatment systems can meet this requirement and the costs of such systems. In December 1995 the North Dakota State Water Commission and the Garrison Diversion Conservatory District published the final report of the "Northwest Area Water Supply Project Chloramine Challenge Study" (1995 challenge study). This report verified the effectiveness of either chlorination/chloramine or ozonation to provide 99.9% (3-log) removal or inactivation of *Giardia lambia* cysts and 99.99% (4-log) removal or inactivation of viruses. The challenge study also concluded that suspended solids do not affect the disinfection power of ozone and chlorine/chloramine, thereby eliminating the need for sand filters.

In the pretreatment of imported water, the raw water would be disinfected near the intake or booster pump station. For this appraisal-level study, only ozone treatment and chlorine/ chloramine treatment were considered as potential disinfection methods to meet treaty requirements, and appraisal-level process designs and cost estimates are provided for these two systems. Other treatment methods may be identified and evaluated in subsequent studies. Disinfection design criteria used in this report are the same as those used for the 15-cfs Lake Audubon Intake/Pump Station/Pretreatment Facility of the Northwest Area Water Supply Study Project (NAWS). Appraisal-level construction cost estimates were determined for 135- and 70-cfs systems and were prorated for the other flows needed in each import alternative.

Each system is sized to satisfy the design criteria for the flow demands discussed for the various features described in chapter 5. Operation of the plant at less than design flow would increase the detention time and increase the effectiveness of disinfection. This is ideal for the ozonation systems but may be a problem for the chorine/chloramine system, in which the amount of disinfection products produced increases with the amount of free chlorine contact time.

Construction costs presented in the summary report are those from the Bureau of Reclamation appraisal-level estimate. The operation and maintenance costs are a combination of the annual estimated costs for a low-head pumping plant, determined by a Bureau of Reclamation program, and a prorated cost per cfs per day of operation as determined from the Houston Engineering study for the NAWS Lake Audubon intake pump facility.

OZONATION AND CHLORAMINATION DISINFECTION SYSTEM

Description

Figure 4.1 shows the process flow of an ozonation treatment system to treat the modeled import flows. In this system, water discharged from each low-head pump flows through an automatic backwashing sediment filter and then into a multiple-stage concrete contact tank, where it undergoes ozonation, oxidation, deozonation, and chloramination before discharge to a high-head pump for conveyance to the Red River watershed. At the peak flow rate, the system provides a 7-minute ozone detention time before deozonation. The concentration of ozone in the reaction portion of the tank is monitored, and if it declines below a set-point concentration — say, 1 ppm — the system automatically increases the ozone injection rate into the contact chamber.

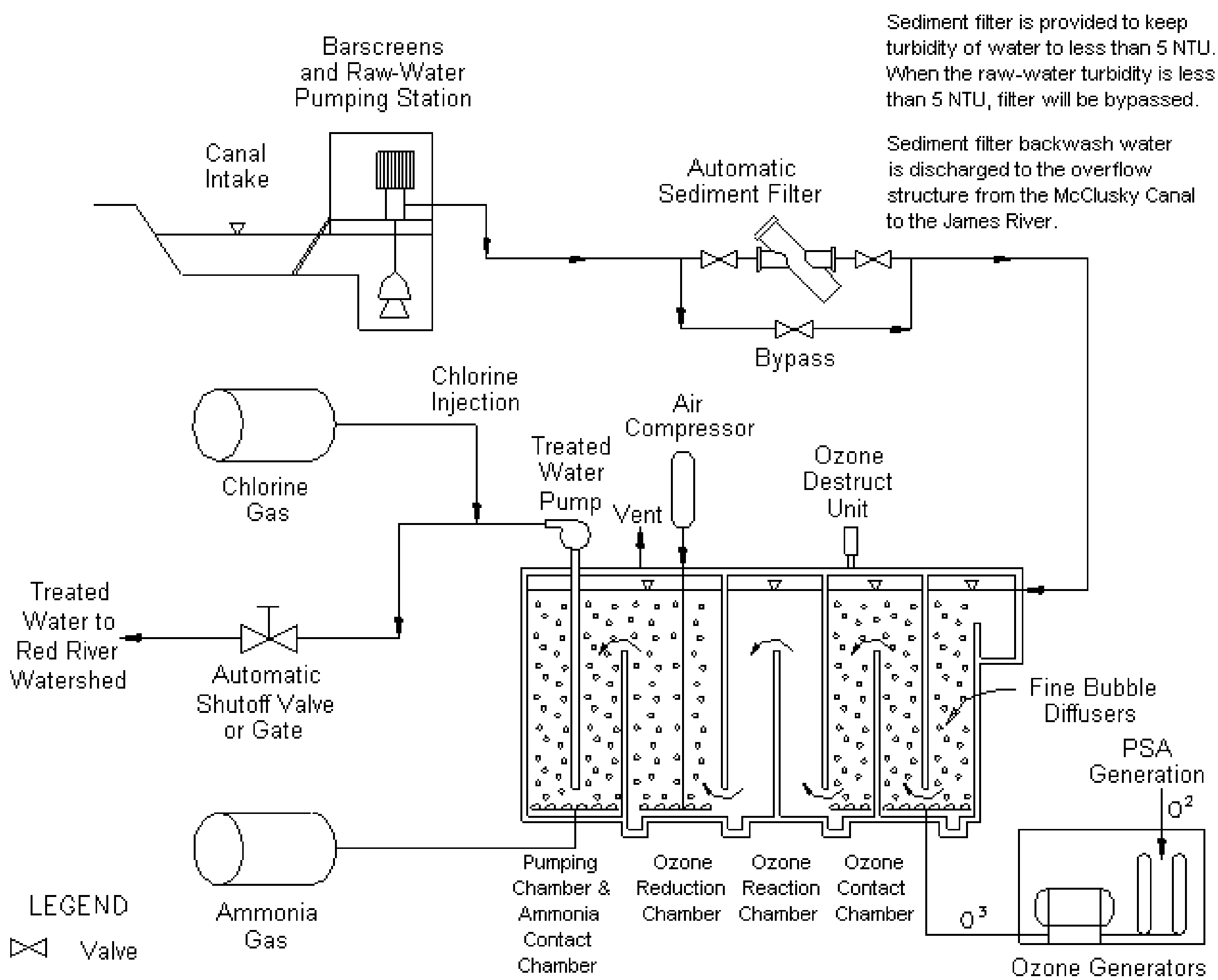

Figure 4.1.—Ozone Disinfection System.

The automatic backwashing sediment filter will be used as needed to provide water at 5 NTU[1] or less turbidity to the ozonation system. The filter would be bypassed if the source-water turbidity is below 5 NTU.

The ozonation process begins with the liquid oxygen storage tank (LOX). The liquid oxygen feeds into the evaporators, which then discharge oxygen gas to the ozone generators. Ozone from the generators feeds into the fine-bubble diffusers, which bubble the disinfectant through the water column within the baffled contact tank. In order to protect the high-head treated-water pump from corrosion caused by dissolved ozone, air is bubbled into the water in the ozone reduction chamber, causing the ozone to diffuse from the water into the air. After deozonation, ammonia gas is bubbled into the water in the ammonia contact chamber, followed by chlorine gas injection into the discharge line from the pump. The ammonia and chlorine provide a chloramine residual of 2.5 mg/L to control biofilm development in the pipeline.

The pretreated water will need to be dechlorinated using a sulfur dioxide injection system prior to discharge or use. A drawback to the chloramine residual requirement is that, after dechlorination, the imported water will have an ammonia concentration of approximately 0.56 ppm, which will increase the oxygen demand at the point of discharge.

Costs

The ozone disinfection system appraisal-level capital construction and operation and maintenance costs for a range of selected flows are provided in figures 4.2 and 4.3. The cost estimates allow for backup units for critical components, including all chemical monitoring and feed systems and an additional liquid oxygen storage tank, which will provide adequate storage for 30 days.

Operation and maintenance of the ozone/chloramine pretreatment system will require certified operators. Actual costs for operators, chemicals and energy will be a function of the amount of time the pretreatment system is operated per year. Figure 4.3 presents the appraisal-level annual operating costs for operation of the treatment system at the design flow all year long. Costs are based on the prorated treatment estimate of $26.50 per cfs per day of operation plus the estimated cost to operate the low-head treatment plant.

The estimated annualized cost (30 years at 6f percent) for operating the ozone/chloramine pretreatment system all year at the design flow ranges from $36.83/acre-ft for the 135-cfs system to $39.67/acre-ft for the 75-cfs system.

[1] Nephelometric turbidity unit—A measure of turbidity based on the amount of light deflected at right angles from a beam projected through a water sample. Water having turbidity greater than 5 NTU is visibly cloudy. U.S. Environmental Protection Agency standards set a limit of 0.5 NTU for turbidity in drinking water.

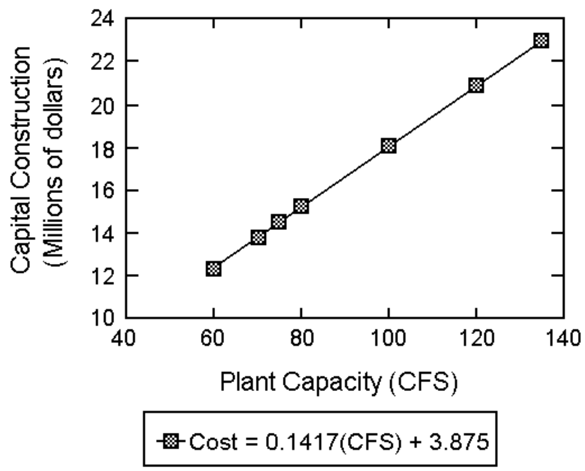

Figure 4.2.—Capital Construction Costs for Ozone/Chloramine Water Treatment Plants.

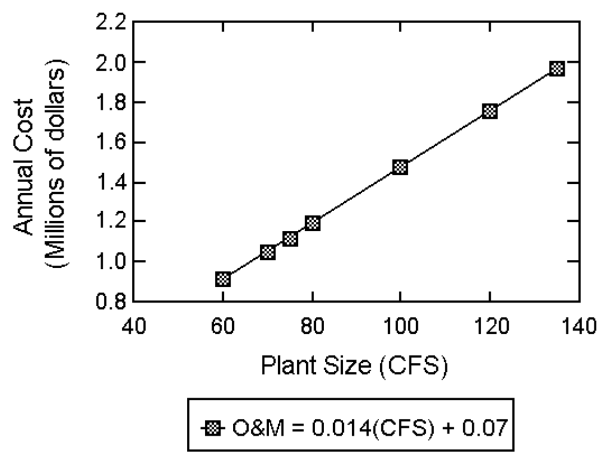

Figure 4.3.—Annual Operation and Maintenance Costs for Ozone/Chloramine Water Treatment Plants (360-day operation).

CHLORINE/CHLORAMINE DISINFECTION SYSTEM

Description

This pretreatment system uses free chlorine to disinfect the water and a chloramine residual to reduce the development of disinfection byproducts. The results of the 1995 Challenge Study demonstrated that disinfection with a chlorine residual of 3.5 to 4.0 ppm for 5 minutes, followed by the addition of 1 part ammonia for every 4 parts of chlorine, followed by a chloramine detention time of at least 3 minutes produces a treated water that meets the biota reduction requirements for water being transferred from the Missouri River drainage to the Red River drainage. It achieves a 3-log reduction of giardia and a 4-log reduction in viruses while producing disinfection byproducts at concentrations less than the maximum allowed in existing (stage 1) and future (stage 2) regulations. A drawback to the use of chloramine for biofilm control is that after dechlorination the imported water will have an ammonia concentration of approximately 1 ppm, which will increase the oxygen demand at the point of discharge.

Figure 4.4 illustrates the process flow of the chlorination-chloramine treatment system described here. After sediment removal by the automatic backwashing filter, the water is chlorinated in the baffled free-chlorine contact tank, which provides 5 minutes of detention at peak flow. The water's free chlorine residual is monitored, and any concentration less than 4.5 ppm automatically increases the chlorine injection rate. Next, the water is detained in the ammonia contact chamber for 3 minutes, where ammonia gas is injected at concentrations of 1.1 to 1.25 ppm to form chloramine, and then it is pumped to the discharge point. A chloramine solution with a total chlorine residual of 4.5 ppm is maintained throughout the pipe. The pretreated water will need to be dechlorinated using a sulfur dioxide injection system prior to discharge or use.

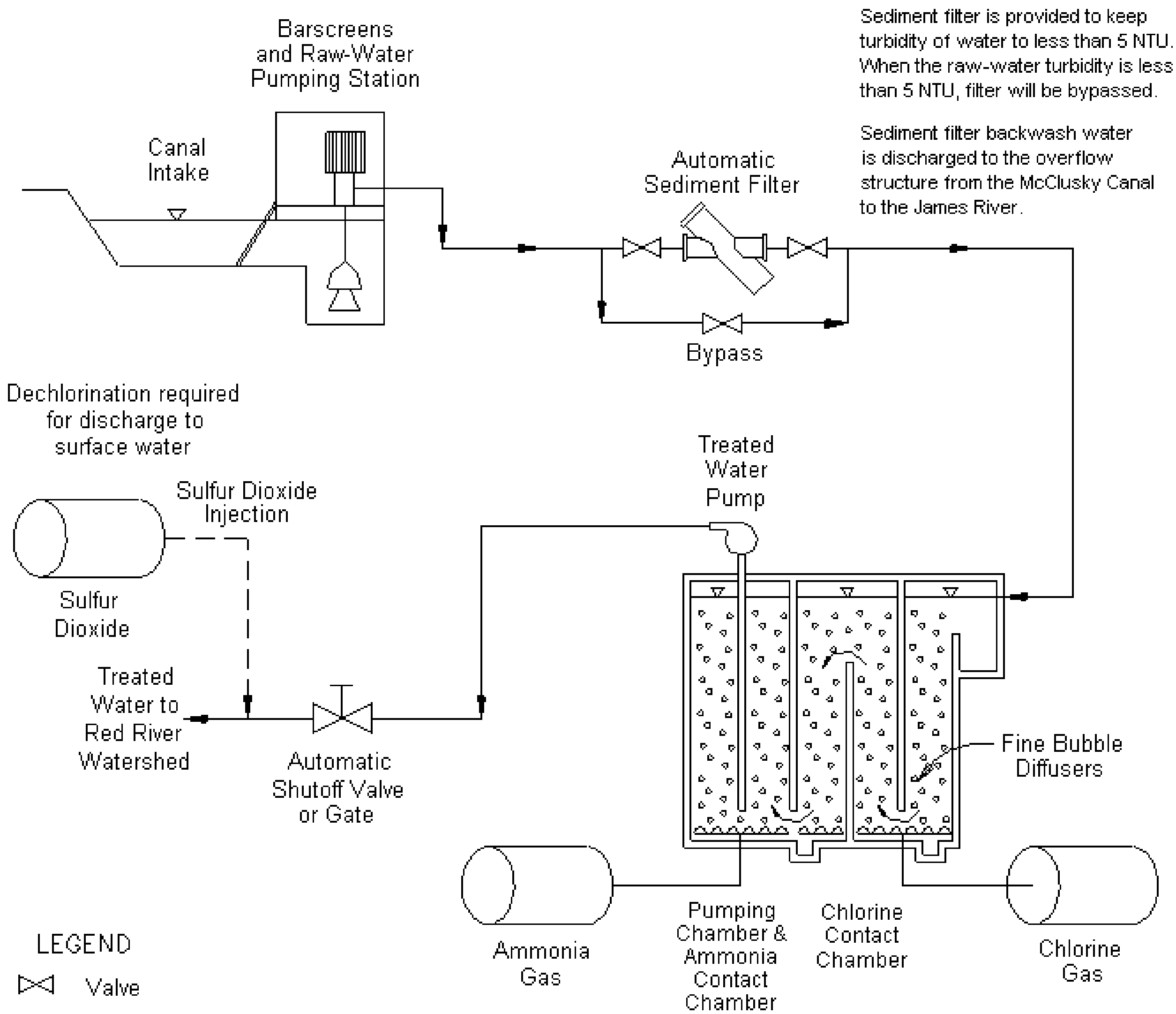

Figure 4.4.—Chlorine Disinfection System.

The automatic backwashing sediment filter is used as needed to provide water turbidity at 5 NTU or less to the chlorine/chloramine system and would be bypassed if the source-water turbidity is below 5 NTU.

Costs

The appraisal-level capital construction cost and annual operation and maintenance costs for the range of imported options are shown in figures 4.5 and 4.6. Operation of the chlorine/chloramine disinfection system would require skilled operators. Actual costs for operators, chemicals and energy will be a function of the amount of time the pretreatment system is operated per year. Therefore, the O&M costs presented in figure 4.6 are based on the yearly operation of the plant at design flows. The estimate for the operation of the treatment system was prorated at $11.70 per day of operation as determined by the NAWS report.

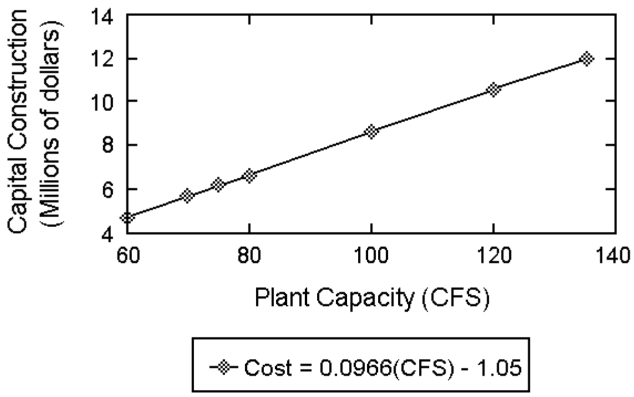

Figure 4.5.—Capital Construction Costs for Chlorine/Chloramine Water Treatment Plants.

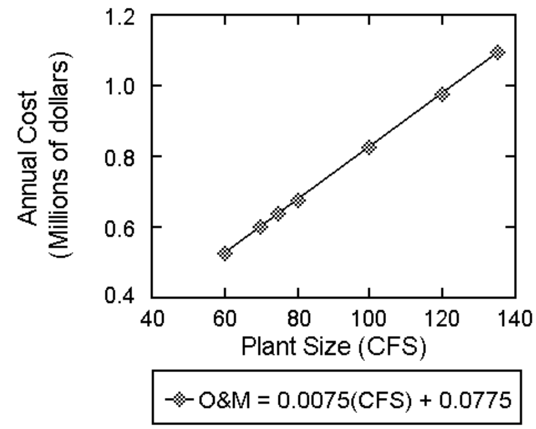

Figure 4.6.—Annual Operation and Maintenance Costs for Chlorine/Chloramine Water Treatment Plants (360-day operation).

The estimated annualized cost (30 years at 6f percent) for operating the chlorine/chloramine pretreatment system all year at the design flow ranges from $19.90/acre-ft for the 135-cfs system to $19.92/acre-ft for the 75-cfs system.

DECHLORINATION

Chlorine in the imported water would have various adverse effects whether it is discharged to surface waters or delivered to a water-treatment plant. In order to reduce these effects, a dechlorination facility will be required for all pretreatment systems. This facility would include a sulfur dioxide injection system, which converts the chloramine compounds to ammonium sulfate and hydrochloric acid.

DISCUSSION OF ALTERNATIVES

Ozonation Followed by Chloramination

Ozone is a powerful oxidant and strong disinfectant, compared to free chlorine. Using this system would reduce the required contact time to meet the required log reduction for giardia and viruses.

Disinfection byproducts (DBPs) are a concern in all chemical disinfection systems. Presently the only regulated DBP of ozone is bromate, which is formed by ozonation of water containing bromide ions. Based on available information, bromide is not at detectable levels in the Missouri River drainage. During certain times of the year, organic material in the water may only be partially oxidized during ozonation, resulting in the formation of aldehydes. The type and concentration of aldehydes depend on the amount of organic matter, the amount of ozone used, and detention time for reaction. In the alternatives in which the treated water is discharged to the

Red River and Lake Ashtabula, the formed aldehydes would be rapidly degraded by natural algae and bacteria. Water pumped directly to a municipal treatment plant may need to be passed through activated carbon filters to remove aldehydes.

In this system, chloramination is required to eliminate biofilm growth in the conveyance system that could use the generated aldehydes as a food source. During plant operation at less than design flows, the resulting increase in ozone contact time would decrease the formation of aldehydes.

Chlorine/Chloramine Disinfection

This disinfection system provides a 5-minute free chlorine residual contact time, which would partially meet the disinfection requirements. The remaining contact time in order to provide a 3-log removal of *Giardia lambia* cysts and 4-log removal of viruses is accomplished by the weaker disinfectant chloramine during conveyance. In order to minimize the production of disinfection byproducts, the chlorine/chloramine disinfection system would need to operate at the design flows, since the disinfection products would increase as free chlorine detention times increase.

Table 4.1 is a summation of the costs for the ozone/chloramine/dechlorination and the chlorine/chloramine/dechlorination pretreatment systems for various alternatives that discharge into surface water within the Sheyenne River drainage basin.

Table 4.1. Appraisal-Level Construction and Operation/Maintenance Costs For Pretreated Water Discharged to the Surface Waters

Design Flow	Treatment method [1]	Construction cost [2]	Annualized cost/acre-ft [3]
135 cfs	O/C/D	$23,000,000	$36.83
	C/C/D	$12,000,000	$19.90
120 cfs	O/C/D	$21,000,000	$37.28
	C/C/D	$10,500,000	$19.90
75 cfs	O/C/D	$14,500,000	$39.67
	C/C/D	$6,200,000	$19.92
60 cfs	O/C/D	$12,000,000	$41.26
	C/C/D	$4,700,000	$19.93

[1] O/C/D = ozone/chloramine/dechlorination process; C/C/D = chlorine/chloramine/dechlorination process.
[2] Construction cost from the Bureau of Reclamation appraisal-level estimate.
[3] Annualized cost for Reclamation's capital construction estimate and the prorated annual operating costs for 30 years at a discount rate of 6f%. Assumes operation of the pretreatment system 12 months of the year at the design flow rate.